Analysis of High Spatial, Temporal, and Directional Resolution Recordings of Biological Sounds in the Southern California Bight

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LONG-TERM GOALS

The long-term goals of this research effort are to detect, localize, and characterize the underwater biological sounds in the Southern California Bight, for the benefit of Navy environmental compliance. The particular focus in this program was on the biological sounds at low to mid frequencies recorded during a large experiment off the southern California coast in 1999. The efforts in this program also support the Ph.D. research of graduate students in marine bioacoustics and ocean acoustics at the Scripps Institution of Oceanography.

OBJECTIVES

The objective of this project was to conduct a set of biologically-focused research efforts using a high quality, high resolution ocean acoustic data set collected in 1999 off the Southern California coast. The data analysis efforts support the thesis research by graduate students at the Scripps Institution of Oceanography (SIO), studying a) the potential impact of man-made sound on the calling behavior of transiting whales in the Southern California Bight, b) the use of passive underwater acoustic techniques for improved habitat assessment in biologically sensitive areas and improved ecosystem modeling, and c) the application of the physics of excitable media to numerical modeling of biological choruses and extension to collective biological behavior. The analysis results characterize the low frequency underwater sonic environment in an area of operational (training) interest to the Navy.

APPROACH

In 1999, a large experiment was conducted off the Southern California coast. This experiment involved the deployment of several horizontal hydrophone line arrays on the ocean bottom. The geometry of the array deployment is shown in Fig. 1. The outputs from these arrays were fiber-optic cabled to shore and recorded continuously for a period of a few months (not all arrays were deployed for all time periods). The complete data set is archived at the Applied Research Labs, University of Texas at Austin (ARL/UT). While ARL/UT was in the process of transcribing their data archive onto newer recording media, they also provided us with a copy of the unclassified portion of this data set.

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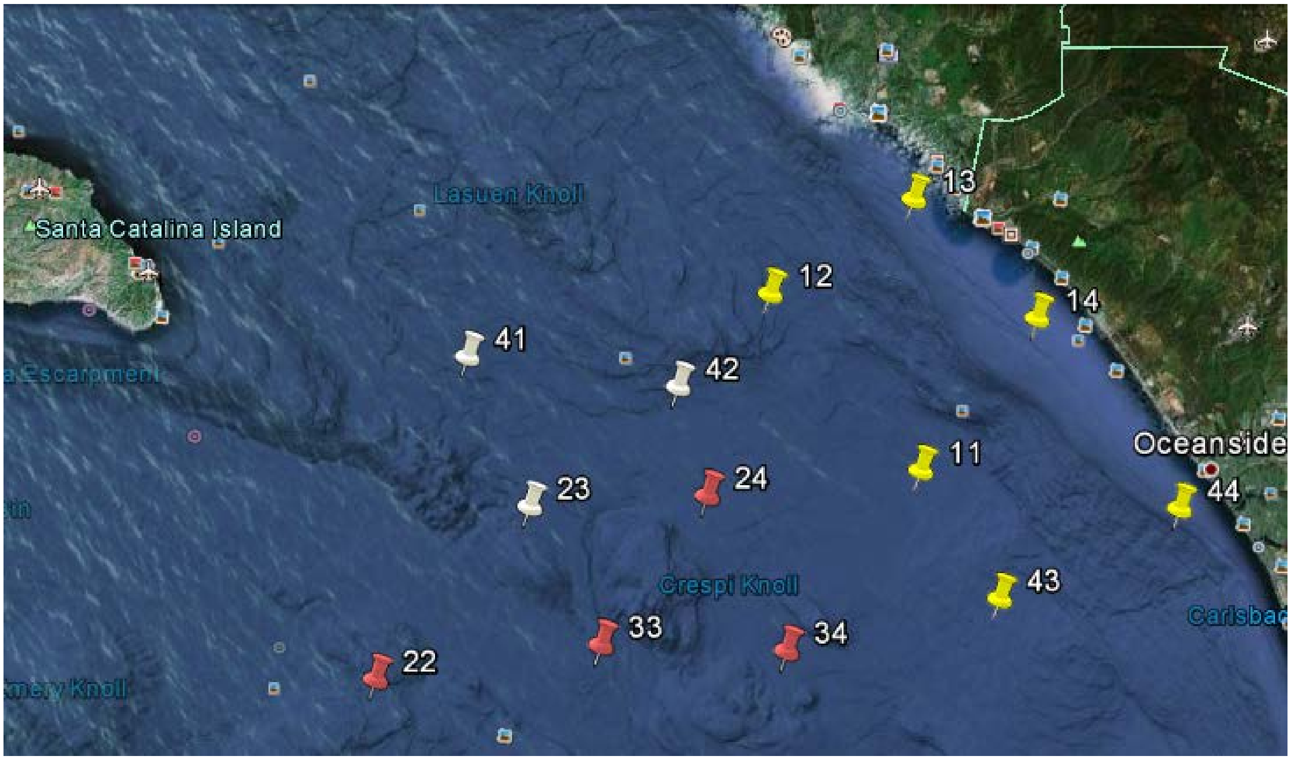

Figure 1. The locations of several of the hydrophone arrays deployed during the large experiment in 1999 off the southern California coast are marked by colored push-pins on this Google Earth map. To the northwest of the array deployment area is Santa Catalina Island. The array number is listed next to each push-pin location. The data from the near-coastal arrays marked by yellow push-pins were recorded on one time base, whereas the red-colored arrays were recorded on a second time base.

One graduate student who worked with these data just finished his Ph.D. thesis in spring, 2013. The overall topic of his Ph.D. thesis was on the potential impact of man-made sounds on the calling behavior of transiting humpback whales in the Southern California Bight. The main scientific hypothesis tested in this research is that the evolution of unit structure and song characteristics in the population of transiting humpback whales in the Southern California Bight is correlated, at least to some extent, with properties of the environment, with particular focus on those properties created by human activities. Results from this thesis research indicated that, after careful calibration of the environmental effects on call detection, the animals increased the energy emitted in calling (either by increasing the call source level and/or the number of calls) in response to increases in noise level.

As part of this research, the "GPL" detector based on a power-law processor was developed (Helble et al., 2012). A power-law processor, not an energy detector, is the optimal detector for transient signals when no *a prioi* knowledge of the arriving signal exists. This algorithm presently is being used to scan the 1999 data set for biologically-created transient signals. Unfortunately, an initial search this past year did not find any humpback whale calls.

A second graduate student whose research will use the data set recently started in the Applied Ocean Science curricular group at SIO. She will continue work initially started by two other students, with a particular focus on the underwater sounds created by fish and invertebrates. This research thrust

involves the integration of passive ocean acoustic measurements with standard methods to improve habitat assessments and ecological monitoring, including ecosystem modeling, and the use of this improved understanding to inform policy makers and resource managers. Presently, the research is involved in examining the relationships between archived oceanographic data, including those from the California Coastal Ocean Fisheries Investigation (CalCOFI) surveys, and the temporal, spatial, and directional properties of the underwater sound field from the data set. The overall scientific hypothesis being tested in this thesis research is that certain properties of passive acoustic recordings provide unique and useful information on the condition of marine habitats.

Initial efforts by an undergraduate environmental engineering student using these data also will benefit the graduate student research described in the previous paragraph. This work involves the application and testing of numerical models of the chorusing behavior of fish and invertebrates. An initial model was developed to predict the unusual spatiotemporal patterns of a biological chorus observed off the Southern California coast in experiments conducted in the mid 1990s. This chorus also is present in the 1999 data, as published in the proceedings of the spring, 2013 Acoustical Society of America meeting (D'Spain et al. 2013). With changes in the input parameters, the model predicts the temporal characteristics of a wide variety of biological choruses. The main goal of the present effort is to relate the best-fit model parameters to properties of the environment and the fishes themselves. An overall scientific hypothesis to be tested is that the properties of biological choruses, characterized by the parameter values in model fits to the data, provide insight into population-level structure and dynamics and trophic interactions of important food sources for certain marine mammal species.

The approach in this project was to a) convert the data into a binary format useable with custom MPL/SIO processing software and with Matlab, b) create wav-format files of the data from a single element of selected sub-arrays to allow rapid visual/auditory scanning with the MPL/SIO "Triton" software, c) make spectrogram plots to provide a pictorial history of the acoustic field properties during the exercise, d) locate periods of time containing biological sounds using spectrograms and the GPL algorithm, e) beamform the array data containing marine biological sounds so that the graduate students would rs do not need access to the sensitive information on array design, and f) place the beamforming results containing biological sounds into a geographic information system (GIS) context (as in Batchelor and D'Spain, 2005). Rather than perform these steps on the complete 1999 data set, which is too large to thoroughly examine in a project of this size, these steps were followed for selected periods of time and for certain frequency bands, depending upon the biological phenomenon under study.

The work in this project was leveraged with other ongoing programs, listed in Related Projects below.

WORK COMPLETED

Although this second year of the 2-year program was budgeted only to cover publication costs, bulk processing of the data set continued, requiring minimal effort since the processing software was developed in the first year. Copies of the remaining unclassified data were received from ARL/UT and converted to a binary format readable by MPL/SIO in-house software and by Matlab. Spectrograms continued to be created for one element of each of the three sub-arrays in an array, and examined to identify periods with biological sounds and other interesting transients for further analysis. These efforts supported both the continuation of the investigation into the unusual night-time fish chorus

(D'Spain et al., 2013), but also initial investigations into the calling behavior of large baleen whales (finback and blue whales) in the southern California Bight.

Ancillary and oceanographic data for the temporal and spatial attributes of the data set were gathered in the first year of this program and placed into a Geographic Information System (GIS) for use in habitat modeling and spatial analysis. The data are in a format compatible with Matlab, with ESRI ArcGIS, and with other data analysis software packages. The types of data assimilated include: bathymetry (from several sources), offshore landforms, marine protected area boundaries, species distribution for several of the fishes, temperature and salinity, and numerous types of satellite-based data, as well as locations of the arrays and HARP data recording packages.

A significant effort was devoted to further studying the spatial, temporal, and spatiotemporal properties of an unusual near-shore fish chorus that occurs only at night. The results from the analysis were published in the conference proceedings for the spring, 2013 Acoustical Society of America meeting (D'Spain et al., 2013). A peer-reviewed publication with these, and subsequent results, is in preparation.

RESULTS

The low frequency fish chorus with cycling amplitude, observed in data from the mid 1990s, also is ubiquitous in the recordings at night from the near-shore arrays in the 1999 data set, particularly arrays 14 and 13 located on the very shallow-water shelf just offshore in Fig. 1. A few conclusions from the analysis of this chorus are:

- The spatial distribution of the received levels and the directionality of the received sounds indicate the primary region of chorusing occurs in the very shallow water region just offshore of the San Onofre Nuclear Generating Station (SONGS);
- The received levels at the arrays 15-20 km offshore (numbers 12, 11, and 43 in Fig. 1) are 15-20 dB lower than the near-shore (approximately 5 km offshore) arrays, indicating that all chorusing occurs in water depths less than 50-100 m;
- Given that the main region of chorusing occurs offshore SONGS, the entrapment studies for the two cooling-water intake systems at SONGS are particularly relevant – they show that the greatest abundance of soniferous fish captured by these intakes are queenfish and white croaker, two physiologically similar members of the family of Sciaenids;
- Although the nighttime chorusing shows an increase in level over the April/May time frame of the 1999 sea test, its directionality as measured by the near-shore arrays differs surprisingly little from one night to next over this period;
- .The spatiotemporal patterns of the chorusing are not as well organized as those observed in the mid 1990s coming from the offshore region south of San Diego Bay. These patterns along with the numerical modeling suggests that the spatial distribution of fish in the region covered by the 1999 arrays has a significantly greater degree of clustering than the (likely) more homogeneous distribution found south of San Diego Bay.

An example bearing-time record (BTR) recorded at night by array 14 is shown in Fig. 2. The sinewy nature of the patterns indicates that the location of chorusing evolves in directionality over the

duration of the chorus. The direction in which a given chorus cycle starts varies somewhat from one chorus to the next. However, the direction with the highest received level (red) remains the same – towards the coast.

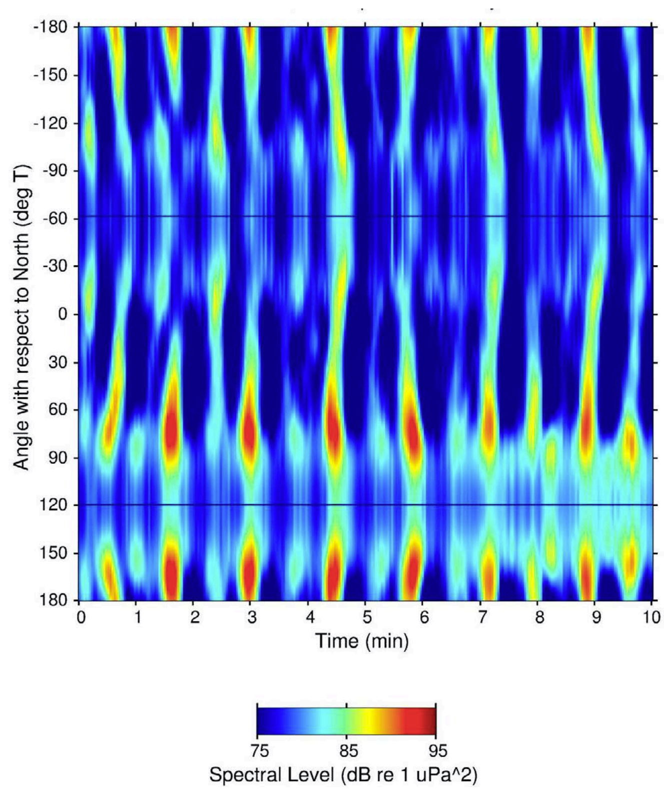

Figure 2. This bearing (angle with respect to true north, on the vertical axis) versus time (on the horizontal axis) plot covers a 10-minute period at night, as calculated from Array 14 data. The spectral density from 300 Hz to 500 Hz was integrated to create this plot. The two horizontal black lines represent array endfire. Both -180 deg (top of plot) and +180 deg (bottom) represent true south.

The single-element spectrograms from the 1999 data set show numerous recordings of biological transients with excellent signal-to-noise ratio. Two example spectrograms are presented below.

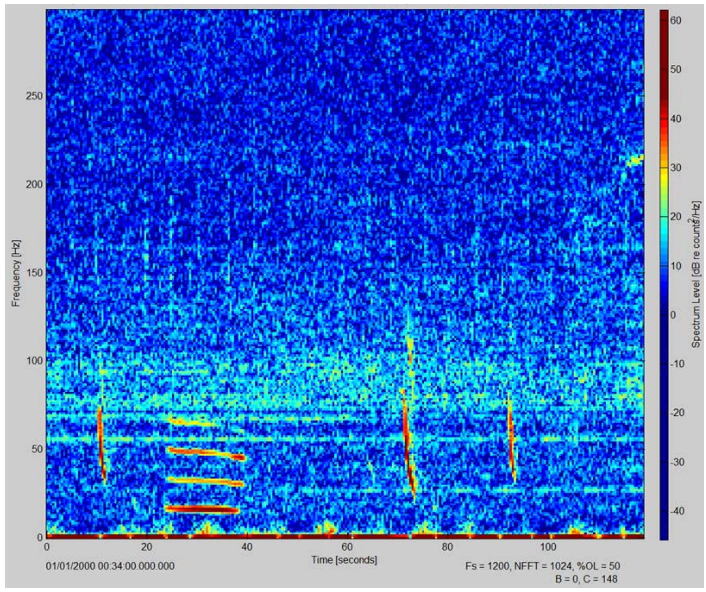

Figure 3. A spectrogram from Array 14, from 0 to 300 Hz (vertical axis) over a 2-min period (time increasing from left to right on the horizontal axis) contains a type B blue whale call (20-40 sec) as well as 3 rapid downsweeps.

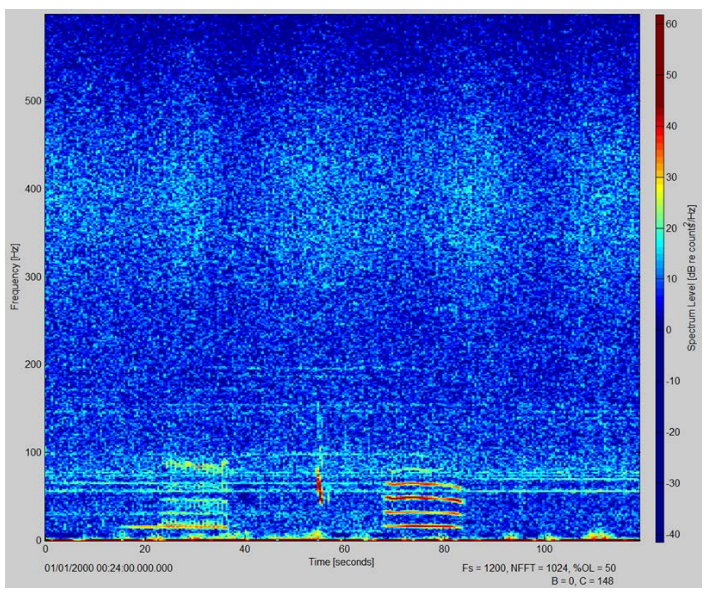

Figure 4. This spectrogram also is of 2-min duration but now covers the frequency range 0-600 Hz along the vertical axis. In addition to two type B blue whale calls, separated by 45 sec or so, and a rapid downsweep below 100 Hz, this plot also contains clouds of energy in the 300-500 Hz band that illustrate the cycling nature of the fish chorus. These data also were collected by Array 14.

IMPACT/APPLICATIONS

The scientific studies enabled by the large 1999 underwater acoustic array data set contribute to a greater understanding of the bioacoustics characteristics and overall ecosystem properties of the Southern California Bight, a region containing a high density of marine mammals, essential fish

habitat, and a high level of U.S. Navy activity. The studies dealing with the potential impact of Navy activities, and human activities as a whole, on marine mammal and endangered species populations in the region is particularly relevant. A natural outgrowth of these studies will be a detailed characterization of the low frequency underwater sonic environment in and near the SOCAL and Camp Pendleton Navy Range Complexes off the Southern California coast. Finally, by supporting the research efforts of graduate students in the field of marine bioacoustics and ocean acoustics, this project has helped provide the Navy with the future generation of highly trained ocean acousticians and bioacousticians aware of both Navy needs and environmental issues.

RELATED PROJECTS

The efforts in this project have been heavily leveraged with other programs. The data archival efforts by ARL/UT provided the opportunity to obtain a second copy of the data tapes. Both the Department of Defense SMART fellowship and other fellowship programs at covered the graduate student costs. Participation by senior-class undergraduate students from the UCSD Environmental Engineering department was arranged by the UCSD Vice Chancellor of Academic Research. Algorithms from the Glider-Based Passive Acoustic Monitoring Techniques in the Southern California Region, Code 322-MBB, with John Hildebrand and Gerald D'Spain as co-PIs, have been, and are being, used to automatically scan the data for marine mammal calls and other biological sounds. Finally, the analyses also have used data from the CalCOFI program at the Scripps Institution of Oceanography.

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